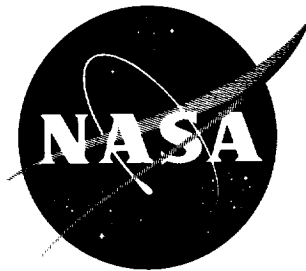


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THE PURPOSES OF ENVIRONMENTAL TESTING FOR SCIENTIFIC SATELLITES

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SUMMARY

The economic necessity of high reliability dictates a major role for environmental testing in the exploration of space. High reliability in spacecraft can be achieved only through extensive environmental testing. Successful testing depends on a comprehensive test plan that is formulated from the requirements of specific programs. Successful satellites and space probes can be achieved most economically by full use of such test programs and by the timely application of object lessons learned from previous programs.

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INTRODUCTION

Reliability is an attribute of a device that cannot be directly measured. In treating reliability numerically, the concepts of probability are introduced; and reliability can be defined as:

The probability of a successful operation of the device in the manner intended and under the conditions of intended customer use.

This definition (Reference 1, p. 20)—and many similar ones—leads to a large number of questions concerning, chiefly, the determining of the required level of "probability" and the defining of criteria for "success."

The required level for the reliability of a satellite is a function of its mission. This paper will discuss the reliability and environmental testing problems that apply to *scientific* satellites as distinguished from spacecraft used for manned space flight or for military purposes. In general, the manned and military missions require a considerably higher degree of reliability than does the scientific one. Unreliability in a scientific satellite implies loss of data; in a manned satellite, loss of life; and, in a military satellite, risk to the nation's defense posture. On the other hand, the scientific satellite is usually more complex, is developed in a short period of time, and carries instrumentation at the highest levels of the state-of-the-art. The problems of reliability assessment are therefore of comparable difficulty for all three categories but are approached from slightly differing points of view.

The objective of the scientific satellite is to make fundamental measurements that cannot be made from the earth. In some cases, these measurements must be made in situ; in others, the instruments must be raised above the distorting effects of the earth's atmosphere, magnetic field, and ionosphere. A given satellite usually carries a set of experiments intended to make *simultaneous* measurements of interest in a given discipline: thus, Explorer VIII (1960 ξ 1) makes direct measurements of the ionosphere, Explorer XI (1961 ν 1) orbits a gamma ray telescope, Explorer XII (1961 ν 1) measures energetic particles, and the Orbiting Solar Observatory I (1962 ζ 1) measures electromagnetic radiation from the sun. A list of satellites and space probes launched by the Goddard Space Flight Center (GSFC) as of December 1962 is attached as Appendix A.

*This paper was prepared at the invitation of the American Society for Quality Control (Washington Section), and was presented Feb. 12, 1963, at the ASQC Reliability Training Program.

In broader terms, Dr. Robert Jastrow (Reference 2) has summarized the intent of NASA's scientific investigations in space as follows:

Although they involve many questions in physical science, nonetheless most of the matters under investigation by space flight vehicles may be grouped around a relatively small number of central problems:

First, problems relating to the structures of stars and galaxies: stellar evolution, nucleosynthesis, the cosmic abundances of the elements.

Second, the origin and evolution of the solar system, the formation of the sun and planets, and the subsequent history of planetary bodies.

Third, the control exercised by the sun over the atmosphere of the earth, the structure of the upper atmosphere, and the causes of weather activity in the lower atmosphere.

The level of reliability that should be required of a satellite whose purpose is to gather data applicable to these fundamental problems is difficult to set. In terms of the usual time scale for evolving new scientific theory from basic data, the scientist is not particularly interested in whether the data come from today's launching or from the launching of the backup flight unit a few months hence. (Favorable planetary orbital conjunctions are an obvious restriction on this freedom in time. However, the "launch window" is often sufficiently long to provide for a second launching.) The circumstance of a backup unit, then, give the impression that the only requirement is a reasonably high probability that at least one of the two units should be successful.

Another problem arises when the question of what constitutes success is considered. Since perhaps five experiments may be flown on even a small satellite, not all experiments are required to work perfectly before the shot is called a success. Furthermore, the required duration for acceptable operation should be defined. For some satellites, transmission of data for a few orbits might suffice. For others, from which we hope to determine expected ranges of the measured parameters, months may be needed.

On the basis of scientific considerations alone, assignment of reliability requirements is impossible. Reliability is fundamentally a ratio; it is used to weigh risk against investment. Traditionally, scientific investigation has been concerned with the gathering of accurate data, subjecting it to rigorous analysis, fitting it to theoretical hypotheses, and subsequently gathering further independent data for verification of the results. Employing satellites as a scientific tool has changed one factor in this process markedly: the *cost* of making the experiment. Expensive tools have been used before (e.g., the cyclotron); however, the "one-shot" nature of the satellite experiment is probably paralleled only by the investigations of the effects of atomic explosions.

With the introduction of cost considerations, we have a basis for stating the satellite reliability problem: A level of performance must be obtained to balance the high cost of an individual firing against the need for obtaining timely, accurate data with a package of minimum weight containing exotic instrumentation.

Typical scientific satellite costs are given in Table 1.

By taking the total dollars budgeted and the total weight of satellites in orbit, an estimate of \$50,000 per pound may be derived for all efforts to date (Reference 3). It is clear, then, that we cannot be promiscuous in launching unproven designs.

A TYPICAL SCIENTIFIC SATELLITE - EXPLORER XII

Before proceeding further with a discussion of reliability, a brief exposition of a typical satellite's makeup is in order. Explorer XII, launched on August 15, 1961,* carried some five experiments and provided 2568 hours of real-time data before it ceased transmitting.

Figure 1 is a picture of Explorer XII. Figure 2 shows a block diagram of the system. A weight breakdown by function is given in Table 2.

*See Appendix A description.

Table 1
Scientific Satellite Costs.*

Satellite	Vehicle	Cost (10 ⁶ dollars)	
		Spacecraft	Vehicle
International II	Scout	1.3	1.0
Explorer XII	Delta	2.7	2.5
POGO	Thor-Agena	11.5	6.5
Advanced OSO	Atlas-Agena	17.0	8.3

*These numerical values are estimates and must not be taken as authoritative.

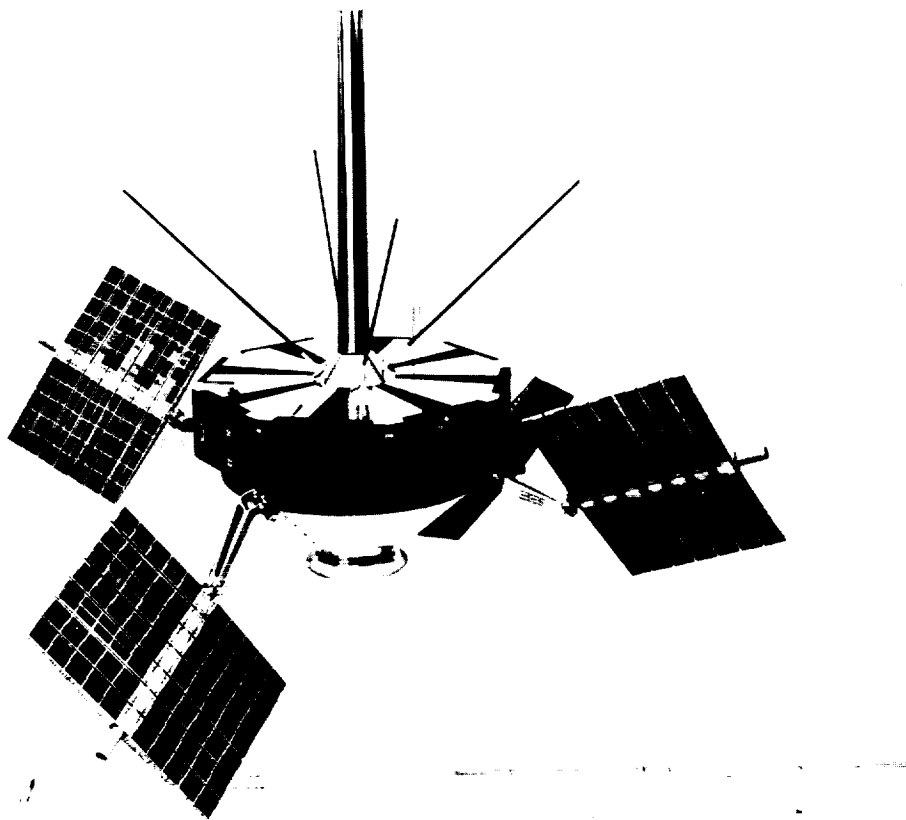


Figure 1—Explorer XII.

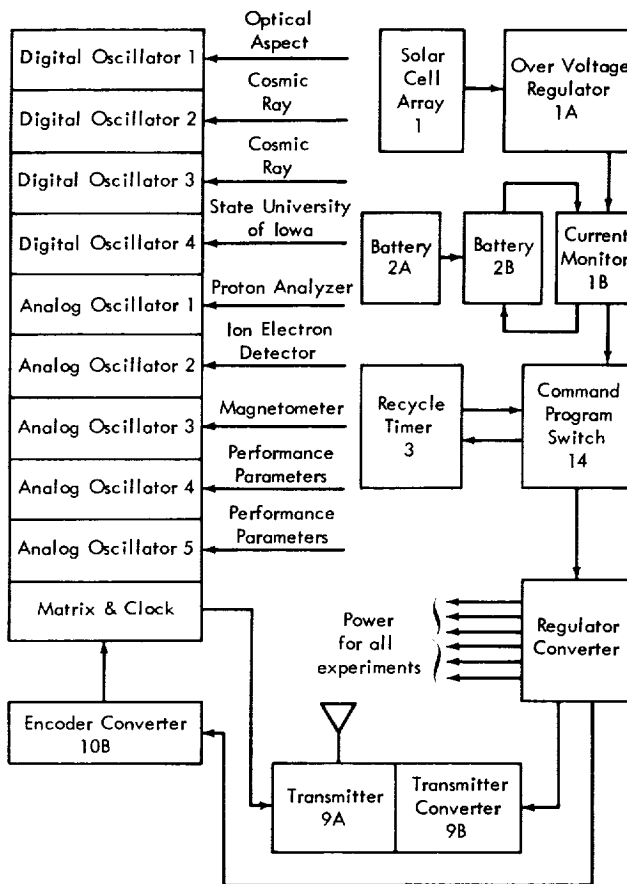


Figure 2—Explorer XII system.

Table 3
Electronic Parts.

Part	Quantity
Capacitors (fixed)	1121
Capacitors (variable)	9
Diodes	813
Resistors (fixed)	2633
Resistors (variable)	11
Transistors	1063
Connectors	70
Inductors	93
Transformers	43
Crystals	2
Switches	10
Solar cells	6144
Total:	12,002

Table 2
Weight Breakdown by Function.

Function	Weight (lb)	Percent of Total Weight
Structure	22.5	27.0
Telemetry	5.5	6.6
Power supply	21.7	26.0
Interface hardware	6.0	7.2
Experiments	27.5	33.0
Total:	83.2	99.8

This basic satellite with different experiments was also successfully flown as Explorers XIV and XV (1962 B 71 and 1962 B 11).

From a reliability point of view, there is nothing striking thus far. There is an electronics package weighing little more than a typical television set. However, a closer look reveals an impressive number of electronic parts (Table 3). It may be taken for granted that these parts are taxed as heavily as the designers dare in an effort both to minimize weight and to perform sophisticated tasks.

MATHEMATICAL MODELS

Lloyd and Lipow (Reference 1, Chapter 9) discuss the establishment of mathematical models of physical systems wherein the reliability of each function of the system can be estimated for a point in time. This type of model can be extended to cover the probability of successful operation as a function of time. The reliability assessment of the Mariner spacecraft by the Planning Research Corporation is a good example of this technique (Reference 4).

After the model is established, empirical data for the expected performance of the individual parts (under predicted electrical and environmental stresses) are inserted. These data are almost always in terms of failure rates as

defined for an exponential distribution (Reference 1, p. 137). By suitable combination of these rates, we may derive the expected *mean time between failures* for the complete system. Table 4 gives such predictions for the Explorer XII spacecraft.

There is a fundamental difficulty in employing the output of a satellite's mathematical model: the applicability of the empirical data used. Because the pace of electronic-parts development has been so rapid, the large sample sizes, uniform populations, and statistical product quality control that must form the basis for the prediction of parts performance do not apply. Or, as was stated recently, "The model is good; if only we had some decent parts data." NASA is now trying to assemble a "preferred parts list" for space applications. However, it is very difficult to tell the designer that he must wait months for qualification testing when a supplier markets a new high-performance device.

At present, then, the mathematical prediction is only indicative. The intent in setting up a model of a satellite system is to highlight those elements of the assembly having the greatest impact on system performance rather than to make accurate quantitative predictions.

TESTING PHILOSOPHY

Satellites not only are *one-shot* but are virtually *one of a kind*. Usually a prototype, a flight unit, and a backup flight unit are the only complete assemblies that are made. Thus, the variations between individual elements and the unpredictable interactions and dependencies that are the curse of accurate mathematical analysis tend to dominate the problem. Therefore, flight unit performance cannot be predicted statistically from the previous test results, and rigorous testing of *the actual flight units* becomes a necessity.

The purpose of environmental testing in a satellite program is to establish the suitability for flight of a given flight unit. Hereafter, we will speak almost entirely of systems tests. Subassembly testing under environmental stresses more severe than those expected in actual use is presupposed. It must be noted here that the difficulty of conducting adequate subassembly

Table 4
Expected Mean Time Between Failures.

Satellite Subassembly	Mean Time Between Failures (10 ⁶ hr)
Overvoltage regulator	0.085
Current monitor	0.16
Batteries A & B	2.5
Recycle timer	0.051
Command program switch (essential components)	0.12
Command program switch (all components)	0.061
Regulator converter	0.012
Encoder converter	0.044
Digital oscillator 1 (optical aspect)	0.030
Digital oscillator 2 (cosmic ray)	0.033
Digital oscillator 3 (cosmic ray)	0.022
Digital oscillator 4 (SUI)	0.031
Analog oscillator 1 (Ames)	0.046
Analog oscillator 2 (I&E)	0.045
Analog oscillator 3 (magnetometer)	0.046
Analog oscillator 4 (performance parameters)	0.020
Analog oscillator 5 (performance parameters)	0.016
Transmitter	0.030

tests of complicated new devices on the time scale of the typical satellite development program is frequently overwhelming. This results in the presence in early systems tests of subsystems that may never have experienced environmental exposures. This fact is particularly true of the experiments themselves.

The emphasis on systems testing is sound on a statistical basis, as pointed out by Lloyd and Lipow in their discussion of experimentation and testing (Reference 1, pp. 350 and 371. There is one point, however, that these authors do not discuss: the fact that, in tests of a complete system, no information is generated as to the input and output sensitivities of individual subassemblies. A marginal condition may exist and remain undetected. Subassembly testing must cover this problem.

SYSTEMS TEST OBJECTIVES

The systems test program for a satellite has six goals:

1. Verification that novel or unproven designs meet performance requirements and have a satisfactory life expectancy
2. Verification that particular samples of previously employed hardware are suitable in a new application
3. Elimination of defects in design, material, or workmanship (i.e., finding the weak links in the chain)
4. Discovery of unexpected interactions between subassemblies when the system is exposed to environmental stress
5. Training of personnel who will be responsible for the satellite at the launching site and who will be responsible for data reduction and analysis
6. Generation of information that will serve as a guide in making new designs and in assessing their reliability

(It should be noted that we do not pretend in any way to *measure* the reliability of the satellite.)

In attempting to reach these goals, despite the limitations, a model of the failure pattern that we might expect to encounter must be formulated. The test philosophy is then based on this concept. Our somewhat limited experience suggests that satellite failures fall into four categories:

1. Early failures caused by a major design weakness
2. Early failures resulting from defects in material or workmanship
3. Random failures whose frequency of occurrence is a function of design and quality control.
4. Wear-out failures

Figure 3 illustrates this failure pattern, which is also discussed by Lloyd and Lipow (Reference 1, p. 416) as being applicable to rocket engines.*

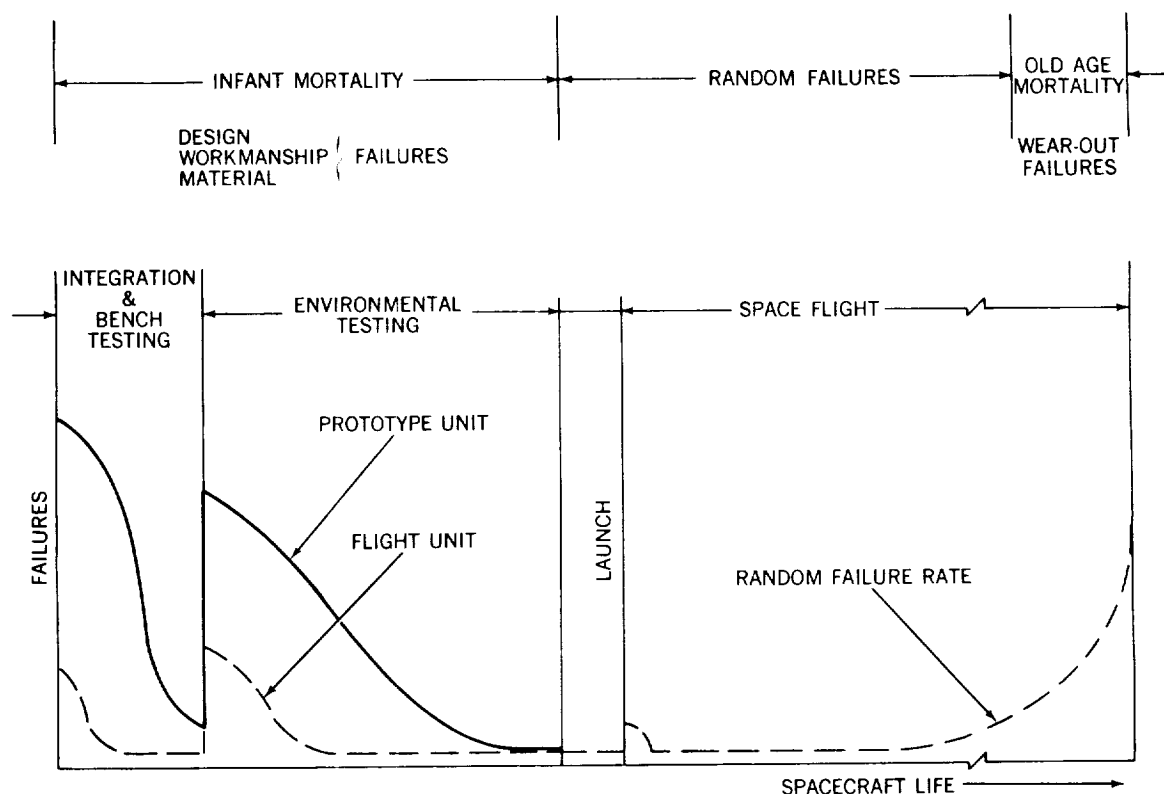


Figure 3—Failure pattern.

The systems test program is directed chiefly at eliminating those failures that arise from the first two causes. Although some insight is gained during the program into the pattern of random failure to be expected, the mathematical reliability analysis (despite its weaknesses) is probably the best guide, after infant mortality has been accounted for, to expected performance. Wear-out caused by exposure to mechanical environments is often covered in the test program. Wear-out caused by other factors—such as surface deterioration under high vacuum—is usually best attacked at a materials, component, or subassembly level because of the extreme cost of conducting extended systems tests.

DESIGN QUALIFICATION (PROTOTYPE) TESTS

In a given satellite development program there may or may not be an electronic breadboard of the complete system. In any case, the *prototype* is almost invariably the first unit in which the

*It should be noted that this failure pattern has been attacked as unsupported by data by many authors (e.g., Cuthill, R. W., "The Reliability Concept and Its Relationship to Performance," American Management Association Report).

subassemblies appear together in their near-final configuration, packaged in their proper relation in the final structure. As Figure 3 indicates, many problems may be expected in integrating the subassemblies into the prototype before a "working" satellite is produced. At some point in the integration of the prototype, the pursuit of perfection in "bench" performance must be discarded in favor of the study of the design's performance in the environmental rigors to be encountered in the prelaunch, launch, and space flight phases of its life. This is a conscious decision on the part of the project manager.

Test of the prototype system are directed toward the *qualification* of a design. It is in this series of tests that failures in the first category (major design weakness) should be eliminated. In attempting design-qualification with one sample, we must break with many traditional environmental test concepts. Overtesting is a necessity but, because of weight limitations, designs cannot be expected to have too great a margin.* Test-to-failure in several environments becomes nearly impossible in the time scale of a typical program. In the face of these problems, prototype test levels are usually established at what might be considered the 99 percent probability level--that is, there should be no more than one chance in a hundred that the flight unit will experience an environment more severe than that employed in prototype testing. The difficulties in setting a 99 percent level in a field as new as space flight are self-evident: Adequate data usually do not exist.

FLIGHT UNIT TESTING

Test of the flight units are directed toward the *acceptance* of a particular system for flight. Because only one prototype has been qualified, virtually no information is available on the variation to be expected between units of the same design. Flight unit testing is intended, then, to discover failures in the second category: defects in material or workmanship. The exposure of flight hardware to severe environments is often attacked as tending to shorten its useful life; but the purpose of the tests is valid, and they must be run. The key to the problem lies in the *duration* of the prototype tests: They must be long enough to give reasonable assurance that flight units can survive the environments imposed both in acceptance testing and in actual launching and flight. In the Pioneer V (1960 α) program, for example, the prototype was subjected to its vibration schedule ten times to gain such assurance. Test levels for the flight units are usually set at the 95 percent probability level; that is, there is 1 chance in 20 that they will be exceeded when the actual launching takes place.

TEST LEVELS

Severity of applied environments has been set at the 99 percent level for *qualification* testing and the 95 percent level for *acceptance* testing. In view of the paucity of available data, we can hardly justify thinking of these levels in statistical terms with carefully computed standard deviations and levels of confidence. Instead, the 95 percent level is usually taken to imply a condition that is

*We must also be aware of another trap in over-specifying environments. For example: A design temperature set arbitrarily high may force the use of low-gain silicon transistors when one-half as many germanium transistors might have done the job. Here, reliability may have been *decreased* rather than enhanced.

supported by the most severe valid data obtained. The 99 percent level is then set at an assumed mean value plus 1.5 times the difference between the mean and the 95 percent level. This procedure is approximately correct mathematically for a normally distributed variable.*

THE TEST PLAN

Environmental testing of a satellite system is an integral part of the development cycle. As such, it must be carefully preplanned to assure that all factors of importance in a given program will be given proper consideration. Because environmental tests come just before launch, the time available for them inevitably shrinks as unexpected problems delay the development program, while launching schedules remain inflexible. In this situation, a valid and comprehensive test plan, approved and directed by management, is needed to prevent errors and omissions during the drive to get acceptable flight units. Corners will be cut unless a clearly defined program has been established previously.

A test plan must first include the procedures by which the system's performance under test is to be evaluated. In practice, there are usually three levels of such a checkout. First, there is what might be termed an *in-line systems check*. (In-line systems are rigorously defined as those whose individual failure would cause failures of the whole system. In practice, the term is usually applied to the power supply, encoding, telemetry, and command receiver systems.) Such a checkout procedure might be used, for example, during a vibration exposure. While survival of vibration is frequently all that is required, anomalies in performance as indicated by an in-line check made during vibration may indicate marginal conditions. Second, there is the *experiment exercise check*. This procedure not only checks the in-line systems but also requires that the experiments be excited in some manner to cause their indicated output to leave the base line. This check might be used at some intermediate point in a vibration test during one of the many changes in setup usually involved. Third, there is the *integrated systems test*, during which experiments are not only exercised but also calibrated. This check is required before and after all major environmental conditionings.

The bulk of a test plan is an exposition of the detailed procedures for applying environmental conditioning to the particular satellite. While general specifications serve as a guide, they cannot be applied indiscriminately.† For example, acceleration levels depend on the weight of the satellite; and the manner of simulating the thermal environment in space depends on the detailed techniques employed in the satellite for temperature control. In establishing the proper procedures for environmental testing, a thorough knowledge of the satellite, the environment, and the capabilities of the test equipment must be available. Improper test technique can lead either to the acceptance of an unsuitable system or to the overdesign of the system to pass an unrealistic test.

A final portion of the test plan is devoted to the criteria for "passing" a test, what procedures are to be followed in the event of certain classes of failures, and the manner in which failures are

*The 95 percent point of a cumulative normal is at 1.65σ . Then, $1.5 \times 1.65 \sigma = 2.47 \sigma$; this is the 99.3 percent point.

†e.g., "General Environmental Test Specification for Delta Launched Spacecraft," Goddard Space Flight Center, Preliminary Draft, November 1962.

to be reported. The failure report system is usually part of a policy that transcends the particular test program. However, the test plan must assure that this procedure is followed to permit the use, in the design of future satellites, of object lessons painfully learned today.

ENVIRONMENTAL EXPOSURES

The selection of the environmental exposures to be applied to a particular satellite during its test program must be made on the basis of an intimate knowledge of its purpose, functioning, and life cycle. Many exposures, levels, and procedures that are meaningful in one application do not apply in others. Many tests included in an environmental test program are operation checks (e.g., a de-spin test) or are in the nature of property determinations (e.g., a moment-of-inertia measurement) rather than environmental exposures. These are included because of the complexity of the facilities involved.

The environments to be considered in planning a satellite test program are illustrated in Figure 4. Assurance of the spacecraft's ability to withstand all *applicable* environments in a given case must be gained. Some aspects may be covered by engineering calculation (e.g., radiation

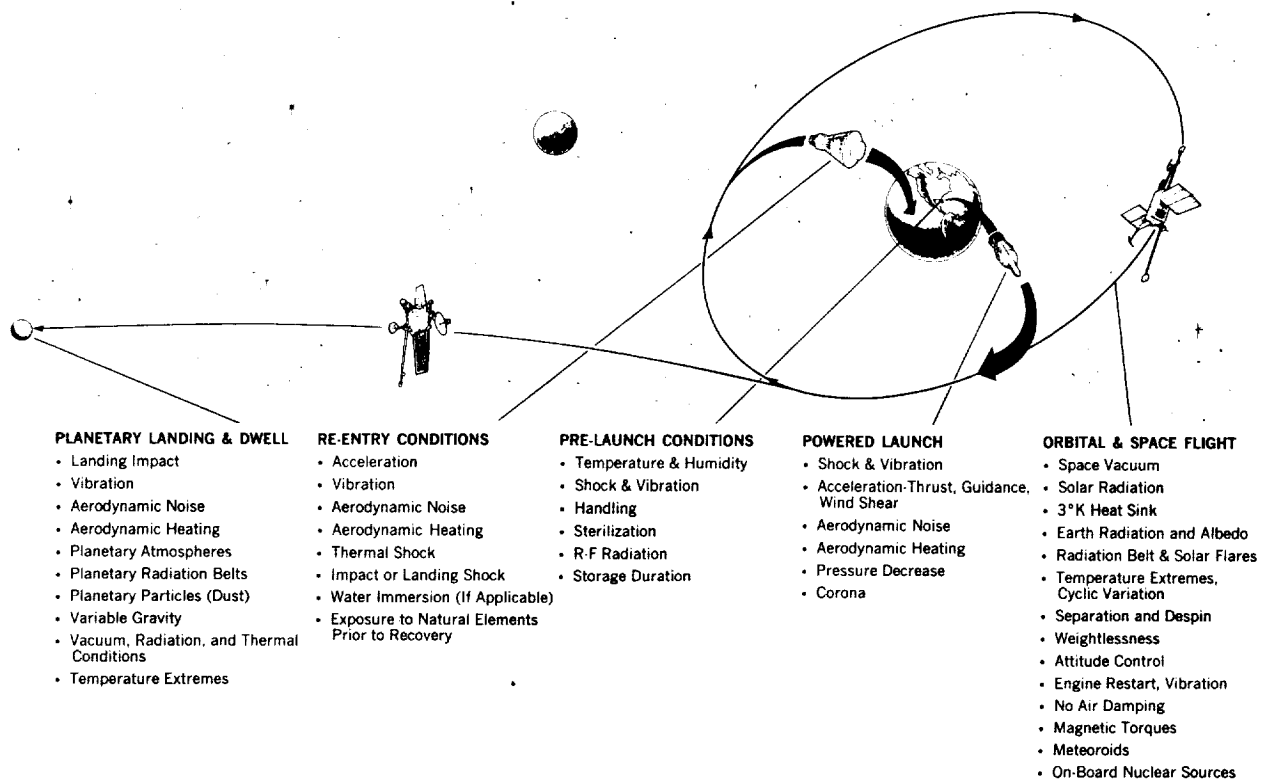


Figure 4—Environmental conditions experienced by space systems.

shielding). Other problems are treated on a subassembly basis (e.g., operation of bearings in ultrahigh vacuum). Systems tests are directed toward those areas in which the interactions of subassemblies will be strongly felt. The following discussion will cover the environmental tests that are most often employed and are believed to be of the greatest significance.

Since qualification testing of the prototype is directed toward verifying the soundness of the system design, this portion of the test program is relatively broad in scope. Typically, the following exposures are included: dynamic balancing and spin (if applicable), acceleration, vibration, shock, temperature, humidity, and thermal-vacuum. On the other hand, acceptance testing of the flight units is intended to uncover significant deviations of these samples from the qualified prototype design—chiefly in the areas of material and workmanship—and to verify that the particular unit is suitable for launching. Usually vibration, thermal-vacuum, and final balancing are the only exposures employed.

Balance and Spin

Dynamic balancing of a spinning satellite is required to assure stability of the spin axis. Even for a stabilized satellite, measurement of its inertial properties and trim-balancing may be required to assure proper performance of the control system. A spin test (for a spinning satellite) is a natural adjunct to balancing, since both tests usually are conducted on the same machine. While we think of satellites as operating in a zero-g environment, at 600 rpm the centripetal acceleration amounts to 10 g/inch away from the center of rotation.

Acceleration

Acceleration tests are quite "straightforward" when the maximum acceleration imparted by the vehicle to a satellite of a given weight is known. A major problem is raised by the fact that most satellites are relatively long compared with the radius of available centrifuges. We must then consider the significance of the acceleration gradient existing in the satellite under test. A more subtle problem arises from the various possible combinations of axial and lateral accelerations that may exist simultaneously.

Vibration

Vibration testing is a compromise of many factors. First, our machines apply vibration in only one direction at a time, in contrast to the actual flight condition; this results in extended test durations. Second, the vehicles currently in use inject both random and quasi-sinusoidal inputs to the satellite; separate tests are frequently required. Third, the final rocket stage and satellite mounting may exhibit a mechanical impedance comparable with that of the satellite; test levels are then conditioned by the properties of the particular satellite. Fourth, the applicability of existing data has been seriously questioned from many quarters. A careful in-flight measurement program for vibration has been undertaken by GSFC in conjunction with its scientific satellite launchings.

Shock

There are two sources of shock for a satellite system: handling, and rocket staging. Neither of these is especially severe in most cases. Normally, a satellite is packaged with reasonable care to mitigate handling shock. Rocket staging rarely results in a pulse representing a velocity change of more than a very few feet per second. Typically, a drop test is used to verify resistance to shock.

Temperature

A temperature test is conducted on the prototype for two reasons. First, we must assure that the system will not be damaged by the temperatures to be encountered in handling, storage, or transit. If a controlled environment is provided by exotic packaging, this must be considered. Second, tests in a temperature chamber provide a first look at performance under expected space conditions. The presence of rapidly moving air, of course, depresses the temperatures to be attained by power-dissipating elements. Nevertheless, experience has shown the test to be very valuable.

Humidity

Satellites are usually subjected to a relatively mild (compared with military specifications) humidity exposure: 95 percent RH at 30°C for 24 hours. The test is used to assure that no permanent damage will be inflicted and to obtain an estimate of the "drying" time that may be involved when the satellite is returned to controlled conditions after exposure to high humidity. Damage to the satellite or excessive recovery times resulting from this test may dictate that the satellite be protected from high humidity at all times.

Thermal-Vacuum

Thermal-vacuum tests attempt to simulate the temperature and pressure environment the satellite will encounter in space. Chamber pressures below 10^{-4} mm Hg are usually considered acceptable, since air conduction is essentially negligible at this level. The study of surface effects that occur at much lower pressures (below 10^{-8} mm Hg) is not a suitable objective for most overall systems tests.

Simulation of the thermal environment is a much more complicated matter. Techniques range from controlling the temperature of the vacuum vessel's wall (soak tests), through predicted temperature contour reproduction and heat flux simulation, to full solar simulation. In choosing the technique for a given test, a detailed knowledge of the thermal control system is required. Further, the distinction between a performance test and a thermal design verification must always be kept clearly in mind.

EXPERIENCE WITH EVALUATION PROGRAMS

The Goddard Space Flight Center has been responsible for the launching of some twenty-six satellites and space probes, as described in Appendix A. These have ranged from the 79-pound

Explorer X (1961 κ) to the 458-pound Orbiting Solar Observatory I. Eight of these satellites have been tested in-house; the remainder has been tested by the prime contractor under GSFC supervision. These programs have molded much of the philosophy discussed herein.

In general, these satellites have been highly successful. They range from six successful TIROS satellites in six attempts to the highly publicized failure of one-half the Relay Communications Satellite (redundancy paid off).

The question now arises as to the contribution of the environmental testing program to these successes. In discussing the reasons for Goddard's success, Dr. J. W. Townsend, Assistant Director for Space Science and Satellite Applications, said*:

The principal cornerstone of our development philosophy has been our belief and reliance in a strong testing program.

- (a) GSFC believes in the FULL SYSTEMS test approach. Every reasonable attempt should be made to test the *entire system* under as realistic conditions as possible and as early in the development cycle as feasible.
- (b) GSFC believes in 100 percent flight acceptance testing at expected average flight levels plus 2σ (95 percent level).
- (c) GSFC believes in testing a flight unit, designated a prototype, at approximately 150 percent of the flight acceptance tests.
- (d) After the testing program, the system should remain intact and last minute changes avoided like the plague (firing jitters problem).

A review of our weekly reports for a 1-year period revealed references to some 266 malfunctions during the testing phase on a dozen satellites and probes. All of these would, of course, not result in outright failure of the mission. It is (very crudely) estimated that 25 percent would have been in this "disaster" category.

Table 5 gives a compilation of the data for five particular cases. The high incidence of pretest checkout failures indicates the pace of a satellite development program and the need to enter systems testing as quickly as possible. The failures under test follow the pattern expected.

From another point of view, we have always had much more difficulty with prototype qualification than was expected. However, there has been much less trouble with the flight units than was feared after the prototype experience.

Table 5
Failures During Systems Test
(Summary for Five Spacecraft).

Test Condition	Type of Failure		
	Electrical	Mechanical	Total
Checkout	12	6	18
Vibration	20	14	34
Temperature	3	--	3
Vacuum	5	--	5
Thermal-Vacuum	51	3	54
Total:	91	23	114

*Internal GSFC memorandum dated January 21, 1963.

ADEQUACY OF TEST LEVELS

Vibration

As discussed earlier, there is considerable uneasiness over the proper levels of vibration to be applied to a given satellite. In-flight success has indicated that they are probably sufficiently high. The failures in flight of one non-in-line subassembly which, having failed to qualify in vibration, was flown anyway suggests that the levels are not excessive. It is believed that the data gathered by our in-flight measurements program will verify these conclusions. The results so far tentatively indicate that the test levels are somewhat low at low frequencies where vehicle structural modes are found and somewhat high at intermediate frequencies.

An unexpected failure of one experiment, probably during the powered-flight phase of the Ariel I (1962 σ) launching, suggests that the testing did not cover adequately the combined effects of acceleration and vibration. This area of combined environmental testing appears to be somewhat weak.

Thermal-Vacuum

Problems exist in both level and duration of thermal-vacuum testing. Recent experience, particularly with Explorer XIV, had indicated that our ability to predict temperatures on the basis of engineering calculation is not particularly good for complicated satellite geometries.* This strongly suggests solar simulation as the desired test method. However, here the test equipment is marginal at best.

In the matter of test duration, there is the quandary of when to stop testing. This is mentioned by Lloyd and Lipow (Reference 1, p. 416 and ch. 16) in their discussion of the development of a test program for a liquid rocket engine. In their case, they were able to project desirable test duration and make reliability estimates on the basis of many tests (approx. 100) of suitably similar devices having the same design. In our case, we have had one similar device: the prototype.

Experience with the more sophisticated satellites now being flown indicates that the 1-year life nominally felt to be desirable is not being achieved. Table 6 shows typical performance. We are attacking this problem on both the design and testing levels. (It might also be noted that timers are being included in many satellites to shut them off after 1 year, to clear the communications channels.)

From the testing viewpoint, there is another duration problem. It will be recalled that our failure model proposes initial testing be long enough to eliminate "infant" faults. Figure 5 (Reference 5) shows experience on three satellites. These data indicate that failures are still occurring at a significant rate as the test ends. Extending the required duration of thermal-vacuum tests is under serious consideration.

*The Jet Propulsion Laboratory encountered a similar problem in their Mariner II (1962 A ρ 1) Venus fly-by.

Table 6
Solar-Powered Satellite Lifetime.

Satellite*	Date Launched	Silent	Life (months)	Remarks
Vanguard I	Mar. 17, 1958	Active	57+	Oldest active satellite; first use of solar cell (weight, 3 lb; two experiments)
Explorer VI	Aug. 7, 1959	Oct. 6, 1959	2	Decayed from orbit July 1961 (weight, 143 lb; eight experiments)
Explorer VII	Oct. 13, 1959	Aug. 24, 1961	26	Tracking beacon ceased on silent date; 20-Mc transmitter still active; clock failed on launch (?) (weight, 92 lb; six experiments)
Explorer XI	Apr. 27, 1961	Dec. 6, 1961	7	All experiments working until silent date; tape recorder never functioned (weight, 82 lb; six experiments)
Explorer XII	Aug. 15, 1961	Dec. 6, 1961	4	Abrupt stop in transmission (weight, 83 lb; ten experiments)
Explorer XIV	Oct. 2, 1962	Jan. 11, 1963	3+	Encoder started malfunctioning Jan. 11, 1963; good data until then (weight, 89 lb; six experiments)
Explorer XV	Oct. 27, 1962	Active	2+	Good data being received on artificial radiation belt (weight, 100 lb; seven experiments)
Ariel I	Apr. 26, 1962	Active	4+	Showed undervoltage problems in Aug. 1962; encoder malfunctioned at times; some data still being received (weight, 132 lb; seven experiments)
Alouette	Sept. 29, 1962	Active	3+	Good data being received; solar cell output diminished by radiation effect (weight, 320 lb; three experiments)
OSO I	Mar. 7, 1962	Active	10+	Data still being received; some problem in positioning control (weight, 458 lb; thirteen experiments)

*The satellite designations for Explorers XI, XII, XIV, XV and for Ariel I have been given with previous text mention; the designations for Vanguard I, Explorers VI and VII, and Alouette are, respectively: 1958 β 2, 1959 δ 1, 1959 ϵ 1, and 1962 B α 1.

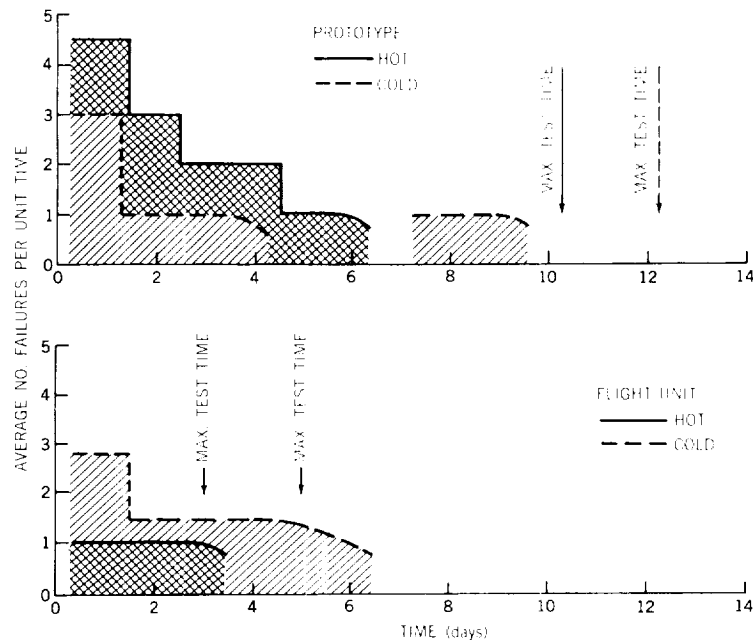


Figure 5—Experience in thermal-vacuum testing.

UTILIZATION OF EXPERIENCE

Currently, utilization on the next program of experience gained in the development and evaluation of a previous satellite is a significant problem. The difficulty is caused largely by the fact that the state-of-the-art is progressing so rapidly that only the most recent experience has application. The problems in instant acquisition, digestion, and dissemination of such information are obviously manifold. We can only say that constant effort is being made to improve the procedures and mechanisms used for this purpose.

CONCLUDING REMARKS

In the foregoing, an attempt has been made to follow the rational used in establishing an environmental test program and to fit this program into the overall satellite reliability picture. Perhaps the most distinctive feature of a satellite test program is that stringent environmental tests of the actual flight units are conducted. The success of the approach is demonstrated by highly successful satellites in orbit.

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Appendix A

Satellite and Space Probe Summary

Goddard Space Flight Center Satellites and Space Probe Projects As of December 1962

Designation	Launch	DATE	Launch Vehicle & Site	Objectives	Instrumentation	Period Minutes	Orbital Elements		Project Manager & Scientist	Experiment	Experimenter	Affiliation	Remarks
							Perigee Miles	Apogee Miles					
EXPLORER VI 1959 Delta I (S-2)	Aug. 7, 1959	Oct. 6, 1959	Thor-Able AMR	To measure three spectra of Earth's radiation belts; Earth's radiation levels; test scanning for Earth's cloud cover; map Earth's magnetic field; measure behavior of radio waves.	Equipment to measure radiation levels; TV-type scanner; micrometeorite detector; two types of magnetometer and detector for space communication experiments.	12 1/2 hours	156	26,357	Dr. John C. Lindsay Dr. John C. Lindsay	Triple coincidence telescopes Scintillation counter Ionization chamber Geiger counter Spin-coil magnetometer Fluxgate magnetometer Aspect sensor Image-scanning television system Micrometeorite detector	J. A. Simpson C. Y. Fan P. Meyer T. A. Fairley Allen Research Laboratories C. P. Sonnett J. Winckler E. J. Smith D. L. Judge P. J. Coleman	U. of Chicago Space Technology Laboratories U. of Minn. STL STL STL STL Cambridge Research/STL	Orbit achieved. All experiments performed. First complete telescope data obtained. Detected large ring of electrical current circling Earth; complete map of Van Allen radiation belt obtained. Weight: 142 lb Power: Solar Life: 2 months
VANGUARD III 1959 Eta	Sept. 18, 1959	Dec. 12, 1959	Vanguard AMR	To measure the Earth's magnetic field, x-radiation from the sun, and space environment through which the satellite travels.	Proton precision magnetometer, ionization chambers for solar x-rays, micrometeorite detector, and thermistors.	130	319	2329		Magnetometer Ionization Chambers Environmental Measurements	J. P. Hephner H. Friedman H. E. LaGow	GSFC NRL GSFC	Orbit achieved. Proton precision magnetometer survey of earth magnetic field over area covered; surveyed location of lower edge of Van Allen Radiation Belt. Actual count of micrometeorite impacts. Weight: 100 lb including attached 5th stage. Power: Battery Life: 85 days
EXPLORER VII (S-1a)	Oct. 13, 1959	Aug. 24, 1961	June II AMR	Variety of experiments, including solar ultra-violet, x-ray, and Earth radiation and micrometeor experiments.	Sensors for measurements of Earth-Sun thermal background, solar x-ray solar radiation detectors; micrometeor detectors; Geiger-Mueller tubes for cosmic-ray counts; ionization chamber for heavy cosmic rays.	101.33	342	680	H. LaGow	Thermal radiation balance Solar x-ray and Lyman-alpha Heavy cosmic radiation Radiation and solar-proton observation Ground-based observations	V. Suomi H. Friedman R. W. Kreplin T. Chubb G. Goetzinger P. Schwed M. Pomerantz J. Van Allen G. Ludwig H. Whipple G. Swenson Dr. C. Little G. Reid O. Villard, Jr. W. Ross W. Dyke	U. of Wisc. NRL Martin Co. Bartol Research St. U. of Iowa U. of Illinois Nat. Bur. of Stand. U. of Alaska Stanford U. Penn State U. Univ. of Calif. Res. Inst. GSFC	Orbit achieved. Provided significant geo-physical information on radiation and magnetic storms; demonstrated method of determining temperature; first micrometeorite penetration of a sensor in flight. Weight: 91.5 lb Power: Solar Life: 26 months

Designation	Launch	DATE	Launch Vehicle & Site	Orbital Elements				Project Manager & Scientist	Experiment	Experimenter	Affiliation	Remarks
				Perigee	Apogee	Period	Instrumentation					
				Miles	Miles	Minutes						
PIONEER V 1960 Alpha	Mar. 11, 1960	June 26, 1960	Thor-Able AMR		Aphelion 92.3 million from sun	311.6 days	High intensity radiation counter; ionization chamber; Geiger-Mueller tube to measure plas- ma; cosmic radiation, and charged particle detectors; micrometeorite and micrometeorite tempera- ture measurements.	Dr. John C. Lindsey Dr. John C. Lindsey	Triple coinci- dence, propor- tional counter, telescope Search coil magnetometer and photo electric aspect indicator Ionization chamber and G-M tube Micrometeorite counter	J. Simpson D. Judge J. Winckler E. Manning	U. of Chicago STL U. of Minn. AFRC	Highly successful ex- periment. First global study of Earth and Venus; established communication record of 225 million miles on 6/26/60; made measurements of solar flare effects, particle energies and distribu- tion, and magnetic field phenomena in replanetary space. Weight: 94.8 lb Power: Solar Life: 3 months
TIROS I 1960 Beta (A-1)	April 1, 1960	June 12, 1960	Thor-Able AMR	428.7	465.9	99.1	One wide and one nar- row angle camera with tape recorder for remote operation. Pic- ture data can be stored on tape or transmitted directly to ground sta- tions.	W. G. Stroud (GSFC) H. Butler (Army)	TV camera systems (2)			Provided 1st global cloud-cover photo- graphs (22,950) of Earth from near circular orbit. Weight: 270 lb Power: Solar Life: 72 days
ECHO I 1960 Iota	Aug. 12, 1960	Still in Orbit	Thor-Delta AMR	945	1049	118.3	Two Mikulack tracking Beacons on sphere.	Robert J. Mackey				Demonstrated use of radio reflector for precision tracking. Suc- cessful transmissions. Visible to the naked eye. Weight: 132 lb (in- cluding inflation pow- der). Power: Passive Life: Still in Orbit
EXPLORER VIII 1960 Xi (S-30)	Nov. 3, 1960	Dec. 28, 1960	June 11 AMR	258	1423	112.7	RF impedance probe us- ing a single grid ion trap; four multiplegid ion traps; Langmuir probe experiment; rotat- ing shutter electric field meter; micrometeorite thermistors for reading internal and surface temperatures of the space craft; and design modifications to reduce spin from 450 to 30 rpm.	Robert E. Bordeau Robert E. Bordeau	RF impedance Ion traps Langmuir probe Rotating-shutter electric field meter Micrometeorite photomultiplier Micrometeorite microphone	J. Cain R. Bourdeau G. Serbu J. Dannelly R. Bourdeau G. Serbu E. Dannelly J. Dannelly M. Alexander K. McCracken O. Berg M. Alexander K. McCracken	GSFC GSFC GSFC GSFC GSFC GSFC GSFC	Measured the electron density, temperature, ion density and com- position of the upper atmosphere and the upper ionosphere. The micrometeorite influx rate was measured. Weight: 90.14 lb Power: Battery Life: 55 days

Goddard Space Flight Center Satellites and Space Probe Projects—Cont. As of December 1962

Designation	Launch DATE	Launch Vehicle & Site	Objectives	Instrumentation	Orbital Elements			Project Manager & Scientist	Experiment	Experimenter	Affiliation	Remarks
					Period Minutes	Perigee Miles	Apogee Miles					
TIROS II 1961 Phi I (A-2)	Nov. 23, 1960	Delta AMR	Test of experimental television equipment leading to eventual world-wide meteorological information system.	Includes one wide angle camera, one narrow angle camera, each with tape recorder for remote operation; infrared sensors to map radiation in various spectral bands; attitude sensor; experimental magnetic orientation control.	98.2	406	431	Dr. R. Stamp	TV camera system (2). Widefield radiometer experiment. Scanning radiometer experiment.	J. P. Heppner T. L. Skiffman C. S. Scarce	GSFC	Orbit achieved. Narrow-angle camera and wide-angle camera transmitted good data. Transmitted 36,156 pictures. Still operative. Weight: 277 lb Power: Solar Life: 76 days
EXPLORER IX 1961 Delta I (S-56a)	Feb. 16, 1961	Scout Wallops Island	To study performance, structural integrity and environmental conditions of Scout launch vehicle and guidance controls system. Inject inflatable sphere into Earth orbit to determine density of atmosphere.	Radio beacon on balloon and in fourth stage.	118.3	395	1405					Vehicle functioned as planned. Balloon and fourth-stage achieved orbit. Transmitter on balloon failed to function. Capable of optical tracking of balloon. Weight: 80 lb Power: Passive Life:
EXPLORER X 1961 Kappa (P-14)	Mar. 25, 1961	Thor-Delta AMR	Gather definite information on earth and interplanetary magnetic fields and their interaction and effect on affected by solar plasma.	Includes rubidium vapor magnetometer, two fluxgate magnetometers, a plasma probe, and an optical aspect sensor.	112 hours	100	186,000	Dr. J. P. Heppner Dr. J. P. Heppner	Rubidium vapor magnetometer & fluxgate magnetometers Plasma probe Spacecraft attitude experiment	J. P. Heppner T. L. Skiffman C. S. Scarce H. Bridge F. Scherb B. Rossi J. Albus	GSFC MIT GSFC	Probe transmitted valuable data continuously for 52 hours as planned. Demonstrated the existence of a geomagnetic storm in the solar wind and the existence of solar proton streams transporting solar interplanetary magnetic field past the earth's orbit. Weight: 79 lb Power: Battery Life: 52 hr.
EXPLORER XI 1961 Rho I (S-15)	Apr. 27, 1961	Delta AMR	Orbit a gamma ray astronomy telescope satellite to detect high energy gamma rays from celestial sources and map their distribution in the sky.	Gamma ray telescope consisting of a plastic scintillator, crystal layers, and a Cerenkov detector; sun and earth shields; temperature sensor; damping mechanism.	108.1	304	1113.2	Dr. J. Kupperman, Jr. Dr. J. Kupperman, Jr.	Gamma ray telescope	W. Kaulhar G. Clark	MIT	Orbit achieved. Detectors and gamma ray telescope transmitted good data. Disproved one part of "steady state" evolution theory. Weight: 82 lb Power: Solar Life: 7 months
TIROS III 1961 Rho I (A-3)	July 12, 1961	Thor-Delta AMR	Develop satellite weather observation system; obtain photos of Earth's cloud cover for weather analysis; determine cloud cover; determine cloud energy absorbed, reflected and emitted by the Earth.	Two wide-angle cameras, two tape recorders, electronic clocks; infrared sensors, five transmitters, attitude sensor, magnetic attitude coil.	100.4	461.02	506.44	R. Rados	Omnidirectional widefield radiometer experiment; scanning radiometer TV camera (2)	V. Suomi	U. of Wisc.	Orbit achieved. Cameras and TV transmitter transmitted good data. Transmitted 35,033 pictures. First hurricane covering international program. Weight: 285 lb Power: Solar Life: 145 days

Orbital Elements

Designation	Launch Date	Launch Vehicle & Site	Objectives	Instrumentation	Orbital Elements			Project Manager & Scientist	Experiment	Experimenter	Affiliation	Remarks
					Period Minutes	Perigee Miles	Apogee Miles					
EXPLORER XII 1961 Union I (S-3)	Aug. 15, 1961	Dec. 6, 1961 Thor-Delta AMR	Investigate solar wind, interplanetary magnetic fields, distant portions of Earth's magnetic field, energetic particles in outer space, and in the Van Allen Belts.	Ten particle detection systems for measurement of protons and electrons and the fluxgate sensors for correlation with the magnetic fields, optical aspect sensor, and one transmitter. Telemetry is provided and transmits con- tinuously.	26.45 hours	180	47,000	P. Butler Dr. F. McDonald	Proton analyzer Magnetometer Cosmic ray Ion-electron detector Solar cell	M. Bader L. Cahill B. O'Brien F. R. McDonald L. Davis G. Longan- ecker	Ames Research Center U. of New Hampshire St. U. of Iowa GSFC GSFC GSFC	Orbit achieved, all in- strumentation operated normally. Coated trans- mitting on Dec. 6, 1961, after sending 2568 hours of real- time data. Received significant geophysical data on radiation and magnetic fields. Weight: 83 lb Power: Solar Life: 4 months
EXPLORER XIII 1961 Chi	Aug. 25, 1961	Aug. 27, 1961 Scout Wallops Island	Testing performance of the vehicle and ground facilities; investigation na- ture and effects on space flight of micrometeor- oids.	Micrometeoroids impact, detectors, transmitter.	97.5	74	722	C. T. D'Aluola	A cadmium sulfate photo- conductor ex- periment. A wire grid experiment.	M. W. Alexander L. Secrest	GSFC	Orbit was lower than planned. Re-entered August 27, 1961. Weight: 187 lb in- cluding 50-lb 4th stage and 12-lb tran- sition section. Power: Solar Life: 2 days
P21 ELECTRON DENSITY PROFILE PROBE (P-21)	Oct. 19, 1961	Oct. 19, 1961 Scout Wallops Island	To measure electron den- sities and to investigate radio propagation char- acteristics of the iono- sphere and 23-Mc under daytime conditions.	Continuous wave propa- gation experiment for trajectory, and an RF probe technique for the descent.		N/A	N/A 4261	John E. Jackson Dr. S. J. Bauer	RF probe	H. Whale	GSFC	Probe achieved alti- tude of 4261 miles and transmitted good data. Electron den- sities were measured about 1500 miles, making the first time such measurements have been taken at this altitude. Weight: 94 lb Power: Battery Life: Hours
TIROS IV 1962 Beta (A-9)	Feb. 8, 1962	June 19, 1962 Delta AMR	Develop principles of weather satellite system; obtain cloud and radia- tion data for use in meteorology.	Two TV camera systems with clocks and recorders for remote pictures, in- frared sensors, heat budget sensors, magnetic zen sensor, north indi- cator.	100.4	471	525	R. Rodas	Omni-directional radiometer. Widefield radi- ometer experi- ment. Scanning radiometer experiment. TV camera system (2)	V. Suomi	U. of Wisc.	Orbit achieved. All systems. Tegea Kinoptic lens used on one com- era. Elget lens on the other. Support to Project Mercury. Weight: 285 lb Power: Solar Life: 131 days

Goddard Space Flight Center Satellites and Space Probe Projects—Cont.
As of December 1962

Designation	Launch DATE	Launch Vehicle & Site	Objectives	Instrumentation	Orbital Elements			Experiment	Experimenter	Affiliation	Remarks
					Perigee	Apogee	Project Manager & Scientist				
	Launch	DATE	Launch Vehicle & Site	Objectives	Period Minutes	Statute Miles	Project Manager & Scientist	Experiment	Experimenter	Affiliation	Remarks
ORBITING SOLAR OBSERVATORY 1962 Delta (S-16)	Mar. 7, 1962	Active	Delta	Placed satellite in Earth orbit to measure solar electromagnetic radiation in the ultra-violet, x-ray, and gamma-ray regions. Investigated effect of dust particles on surfaces of spacecraft.	Devices to conduct 13 different experiments for study of solar electromagnetic radiation, dust particles in space and characteristics of radiation characteristics of spacecraft surface materials.	96.15	343.5	369	Dr. John C. Linday	GSFC	Orbit achieved. Experiments transmitting as programmed.
			AMR				Dr. John C. Linday	0.510 Mev gamma ray spectrometer; 20-100 ke x-ray monitor; 1-8A x-ray monitoring	K. Frost W. White	GSFC	Weight: 458 lb Power: Solar Life: Active
								Dust particle experiment	M. Alexander C. McCracken	GSFC	
								Solar radiation experiment, solar ultraviolet	W. White K. Hallam		
								Solar gamma rays, high energy distribution	W. White K. Frost	GSFC	
								Solar gamma rays, low energy distribution	J. R. Winkler L. Peterson	U. of Minn.	
								Solar gamma rays, high energy distribution	M. Svedoff G. Fazio	U. of Rochester	
								Neutron monitor experiment	W. Hess	U. of Calif.	
P21A ELECTRON DENSITY PROBE (P-21A)	Mar. 29, 1962	Mar. 29, 1962	Scout Wallops Island	To measure electron density profile, ion density, and type of ions in the atmosphere.	A continuous wave propagation experiment to determine electron density and associated parameters of ionosphere. A radio frequency probe for direct density and a positive ion experiment to determine ion concentration under nighttime conditions.	N/A	N/A	3910	John E. Jackson Dr. S. J. Bauer	GSFC	Afforded night-time observations. Characteristic of ionosphere where differ daytime state when the temperature of the ionosphere is much cooler. See P-21
								CW propagation	S. Bauer	GSFC	Weight: 94 lb Power: Battery Life: Hours
								RF probe	H. White	GSFC	
								Ion traps	P. Bourdeau E. W. Doolittle J. Donnelly G. Serbu	GSFC	
ARIEL INTER. NATIONAL SATELLITE (UK 1) (S-51)	April 26, 1962	Active	Delta AMR	To study ionosphere and cosmic rays relation.	Electron density sensor, solar aspect monitor, cosmic ray detector, ion mass sphere, Lyman-alpha gages, tape recorder, x-ray sensors.	100.9	242.1	754.2	R. C. Baumann Robert E. Bourdeau		Orbit achieved. All experiments except Lyman-alpha transmission experiment completed. First international satellite. Contains six British experiments, launched by American Delta vehicle.
								Electron density sensor, solar aspect monitor, cosmic ray detector, ion mass sphere, Lyman-alpha gages, tape recorder, x-ray sensors.			Weight: 150 lb Power: Solar Life: Active
								Ion mass sphere.			
								Lyman-alpha gage.			

Designation	Launch DATE	Launch Vehicle & Site	Objectives	Orbital Elements				Project Manager & Scientist	Experiment	Affiliation	Remarks
				Period Minutes	Perigee Miles	Apogee Miles	Station Miles				
TIROS V 1962 Alpha Alpha One (A-50)	June 19, 1962	Active Delta AMR	Develop principles of weather satellite system; obtain meteorological data and radiation data for use in meteorology.	100.5	367	604		R. Rados	TV camera systems (2)		Launched at a higher inclination (58°) than previous TIROS satellites to provide additional coverage. Two of launch chosen to include normal hurricane season for South Atlantic. IR sensor inoperative, but other systems transmitting good.
											Weight: 285 lb Power: Solar Life: Active
TELSTAR NO. 1	July 10, 1962	Active Delta AMR	Joint AT & T investigation of wide-band communications.	157.8	592.6	3503.2		C. P. Smith, Jr.			Orbit achieved. Television and voice made with complete success. Bell Telephone Laboratories provide spacecraft and ground stations. Canadian Government to be reimbursed for cost incurred.
											Weight: 175 lb Power: Solar Life: Active
ALOUETTE SWEPT FREQUENCY TOPSIDE SOUNDER (S-27)	Sept. 29, 1962	Active Thor Agna PMR	To measure the electron density distribution in the ionosphere at altitudes between 180 miles and 620 miles. To study the variations of electron density distribution with time of day and with latitude, under varying magnetic and solar conditions; and with particular emphasis on high latitude effects. To determine electron density in the vicinity of the satellite by means of galactic noise measurements, and to make observations of related physical phenomena: aurora, magnetic storms, cosmic rays, etc.	105.4	620	638		John E. Jackson	Diurnal hour to hour change. Electron density. Ionization. Whistler experiment.		The ALOUETTE satellite is a project of the Canadian Defense Research Board. The project is part of NASA's Topside Sounder Program. This will be NASA's first satellite to be launched from the Pacific Missile Range, 80.84 inclination. ALOUETTE is designed and built by any other country than the U.S. and USSR.
											Weight: 320 lb Power: Solar Life: Active
TIROS VI (A-51)	Sept. 18, 1962	Active Delta AMR	To study cloud cover and earth heat balance; measurement of radiation in selected areas; and to develop meteorological satellite system.	98.73	425	442		R. Rados	Medium angle camera after taking 1074 pictures.		Inclination 58.3°, velocity perigee 16,822, apogee 16,756. Weight: 300 lb Power: Solar Life: Active

Goddard Space Flight Center Satellites and Space Probe Projects—Cont. As of December 1962

Designation	Launch DATE	Launch Vehicle & Site	Objectives	Instrumentation	Orbital Elements			Project Manager & Scientist	Experiment	Experimenter	Affiliation	Remarks
					Period Minutes	Perigee Miles	Apogee Miles					
ENERGETIC PARTICLES SATELLITE EXPLORER XIV (S-3a)	Oct. 2, 1962	Delta AMR	To describe the trapped solar particles, cosmic radiation, and the solar winds, and to correlate the particle phenomena with the magnetic field observations.	An octagon-walled platform containing three orthogonally mounted magnetometers and radiation coils is located on a boom forward of the platform. Telemetry is PFM and transmits continuously.	37 hours (21.5 minutes)	175	61,226	Paul G. Marotte Dr. Frank B. McDonald	Cosmic ray experiment Ion detector experiment Solar cell experiment Probe analysis Trapped radiation experiment Magnetometer experiment	F. McDonald L. Davis G. Longon-acker M. Boder B. O'Brien L. Cahill	GSFC GSFC GSFC Ames St. U. of Iowa U. of New Hampshire	Velocity of apogee 300 mph, perigee 23,720 mph, inclination to Equator 33°. Weight: 86 lb Power: Solar Life: Active
EXPLORER XV (S 3-b)	Oct. 27, 1962	Delta AMR	To study new artificial radiation belt created by nuclear explosions.	Similar to Explorer XII.	5 hours (C. 31.5 min)	195	10,950	Dr. John W. Townsend Dr. Wilnot Hess	Electron energy distribution Omnidirectional detector Angular distributor Directional detector Ion-electron detector Magnetic field experiment Solar cell gage	W. Brown V. Desai C. McIlwain W. Brown C. McIlwain L. Davis L. Cahill H. K. Gummel	Bell Telephone Laboratories U. of Calif. Bell Telephone Laboratories U. of Calif. GSFC U. of New Hampshire Bell Telephone Laboratories	Good data received on artificial radiation belt. Weight: 100 lb Power: Solar Life: Active
RELAY (A-16)	Dec. 13, 1962	Delta AMR	To investigate wide-band communications between ground stations by means of low-altitude orbiting space craft. Communications signal to be evaluated with respect to absorption of television signals, multi-channel telephony and other communications.	The spacecraft will contain an active communications receiver and retransmit the U.S. and European communications between the U.S. and Europe, and will be used to assess radiation damage to solar cells.	185.09	819.64	4612.18	Joseph Berliner Dr. R. C. Waddel	First TV transmission U.S. to Europe, Jan. 7, 1963			Wide-band Stations: Rumford, Maine; Pleuroville, N.Y.; Gaothilly, England; Weilheim, W. Germany. Narrow-band stations: Nutley, N.J.; Rio de Janeiro, Brazil. Inclination 47.47°. Weight: 185 lb Power: Solar Life: Active

